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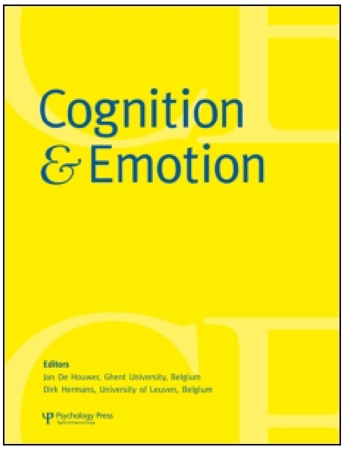

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How automatic is "automatic vigilance"? The role of working memory in attentional interference of negative information

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Whereas attentional interference of negative information has previously been assumed to be automatic, the present research hypothesised that this effect depends on the availability of working-memory resources. In two experiments, participants judged the gender of angry versus happy faces. Working-memory load was manipulated by the presence or absence of a math task (Study 1) or mental rehearsal of a one- versus 8-digit number (Study 2). The results showed that angry faces interfered more with gender naming than happy faces, but only when working-memory load was low. As such, attentional interference of negative stimulus features can be modulated by top-down attentional control processes.

Keywords: Working memory; Automatic vigilance; Emotion.

Negative information draws attention more readily than positive or neutral information (Öhman, Flykt, & Esteves, 2001; Pratto & John, 1991). Regardless of whether it is a snake in the grass, an angry face in a crowd, or a fly in the ointment; negative stimuli have the power to disrupt people's ongoing activities and to make them wonder what is going on. Apparently, the human mind is configured such that people instantly notice potential dangers in their environment (Öhman, 2007).

The attention-grabbing power of negative information has recently become the focus of experimental research. In one pioneering series of studies, people were slower to name ink colour of negative words than of positive or neutral words (Pratto & John, 1991). This attention-grabbing

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effect of negative information has been replicated numerous times, across different tasks and different types of stimuli (Eastwood, Smilek, & Merikle, 2003; Öhman et al., 2001; Smith, Cacioppo, Larsen, & Chartrand, 2003). To account for these findings, theorists have proposed that detecting threats was vital to the survival of our pre-human ancestors. Natural evolution may thus have equipped people with an *automatic vigilance* mechanism (Pratto & John, 1991), that rapidly and unintentionally screens the environment for potential dangers (Dijksterhuis & Aarts, 2003). This vigilance for negative information may thus be part of the innate functional architecture of the human brain (Anderson & Phelps, 2001; Öhman, 2007).

Attending to negative information is fast and unintentional. But is it truly unavoidable? Perhaps not. The type of stimulus-driven perceptual processing that underlies interference of negative information is known as bottom-up attentional control (Yantis, 2000). Recent theories of human cognition suggest that attention is not always under the influence of bottom-up processes. Indeed, attention can also be directed by top-down processes that control attention in accord with people's current plans and behaviours (Corbetta & Shulman, 2002). Although the balance between top-down and bottom-up processes may vary, most tasks involve a combination of both influences. Thus, the question arises whether attention to negative information may be guided by top-down processes.

If top-down processes guide attention to negative information, then changes in the processing demands of a central task can be expected to modulate attentional interference of negative information. Consistent with this, recent research has demonstrated that task load moderates attentional interference of negative visual distracters (Erthal et al., 2005; Okon-Singer, Tzelgov, & Henik, 2007; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002). For example, in one study (Erthal et al., 2005), negative visual distracters slowed down participants' judgements whether two bars were like oriented or not, but only when the difference in orientation of the two bars was substantial. When the orientation of the two bars differed only slightly, such that the central task became more demanding, negative visual distracters no longer interfered with the visual judgement task. In a neuroimaging study using a similar paradigm, brain regions responding differentially to emotional faces, did so only when task load was low (Pessoa et al., 2002).

Although increased task load may reduce attention to negative information, the precise mechanism that underlies this effect is unclear. In the present work, we suggest that attention to negative information is controlled by working memory processes. Working memory is an assembly of mental structures and processes that are used for temporarily storing and manipulating information (Baddeley, 1986). Unitary store models of working memory (Barrouillet, Bernardin, Portrat, Vergauwe, & Campos, 2007; Conway & Engle, 1994) have proposed that because working-memory capacity is limited, different types of information compete over its resources. Under high processing load, working memory facilitates attention to task-relevant information at the expense of task-irrelevant information (Knudsen, 2007; Lavie & De Fockert, 2005). As such, working memory can override more unintentional, stimulus-driven responses. Therefore, it is conceivable that attention to salient, but task-irrelevant, negative information is similarly subject to top-down control by working-memory processes.

In recent years, the idea that working memory is involved in processing negative information has received growing support. Specifically, studies have shown that loading working memory can reduce the emotional impact of negative stimuli (Erber & Tesser, 1992; Van Dillen & Koole, 2007). For instance, negative stimuli induce less negative feeling when the pictures are followed by a task that makes high rather than low demands on working memory (Van Dillen & Koole, 2007). Likewise, negative stimuli lead to smaller neural responses in the amygdalae, an important circuit in the emotional brain, when people perform a demanding working memory task (Erk, Kleczar, & Walter, 2007; Van Dillen, Heslenfeld, & Koole, 2008). Findings of this sort suggest that working memory plays a major role in dealing with negative information.

A working memory account can easily accommodate past findings that task load can reduce interference of negative information (e.g., Erthal et al., 2005). Specifically, when task load is high, working memory may facilitate attention to task-related information at the cost of task-irrelevant information. However, a working memory account also goes beyond prior work in several ways. First, prior work has typically investigated the competition over attentional resources between task-related and emotion-related information in the visual field. Yet, an important function of working memory is to maintain task-related information even when the task itself is not visually present, for example, during mental rehearsal (Knudsen, 2007). Thus, working memory may still modulate attention to negative information when task load is mentally rather than visually represented. Second, working memory not only controls the direction of attention to objects in the visual field. Indeed, working memory may also control attention to certain features of an object (Liu, Slotnick, Serences, & Yantis, 2003). Under high working-memory load, task-relevant features will thus receive more attention than task-irrelevant features. If working-memory processes are involved, then loading working-memory capacity may disrupt attentional interference of task-irrelevant negative features, even when the object itself is in the focus of visual attention.

We designed the present research to investigate the above predictions about the role of working-memory resources in the interference of negative information. We conducted two studies using a modified emotional Stroop task. In this task, participants judged the gender of a series of angry and happy faces. Because emotional expressions are irrelevant to gender naming, longer response latencies to negative compared to positive faces indexed greater attentional interference of negative stimulus features (Pratto & John, 1991). In Study 1, we manipulated working-memory load by varying the presentation of a math equation. In Study 2, we manipulated working-memory load by varying the digit-span of numbers that participants had to retain (Sternberg, 1966). In both studies, working-memory load was induced prior to the gender-naming task, such that there was no competition between task-related and emotional objects in the visual field.

Overall, working-memory load was expected to induce a general slow-down in response times (Barrouillet et al., 2007). More importantly, however, we expected that working-memory load would moderate attentional vigilance for negative information during the gender-naming task. Under low working-memory load, we predicted that participants would display vigilance for negative but task-irrelevant stimulus features (cf. Pratto & John, 1991), such that they would respond more slowly to angry faces than to happy faces. By contrast, we predicted that vigilance for negative stimulus features would be eliminated under high working-memory load, such that participants would respond equally fast to angry and happy faces.

STUDY 1

Method

Participants and design

Forty-one paid volunteers at the VU University Amsterdam (30 women, 11 men, average age 21 years) took part in the experiment. The experimental design was 2 (Math Task: no task vs. math task; within participants) $\times 2$ (Target Expression: positive vs. negative; within participants). The main dependent variables consisted of participants' math performance (both correct responses and response times) and their response times to the gender decision task.

Procedure and equipment

Upon arrival in the laboratory, participants were led to individual cubicles with a personal computer. The experimenter explained that all instructions would be administered via a computer program and left. After a brief introduction, participants proceeded with a gender-naming task in which participants had to indicate the gender of pictures of either male or female faces displaying either a happy or an angry expression. The faces were drawn from The Karolinska Directed Emotional Faces (KDEF) database

(Lundqvist, Flykt, & Öhman, 1998). We selected pictures of fourteen individuals (7 men and 7 women) facing directly into the camera and displaying either a happy or angry expression. Accordingly, the total set consisted of 28 pictures. Each of the pictures was displayed twice; once without a math task, and once accompanied by a math task. Trials with and without a math task were presented in a random order.

The gender-naming task consisted of 56 trials. Each trial was announced by a row of four asterisks (****), which remained in the centre of the screen for one second. Before the 56 experimental trials, participants first received four practice trials to become familiar with the task. During each trial, a picture of either an angry or a happy male or female face appeared on screen for 2 seconds. Participants had to decide as quickly as possible, by making a keyboard response, whether the face on the screen was male or female. In half of the trials (28 trials), the gender-naming task was combined with a math task, which places considerable demands on working memory (Ashcraft & Kirk, 2001). The math task consisted of a moderately complex equation, such as "$4 \times 8 + 11 \ = ?$". Each equation combined a summation or subtraction with a product or a division and was presented on screen for 5 seconds. In the other half of the trials, participants were presented with a blank screen for the duration of the math equation. In these trials, participants thus only performed the gender-naming task. Trials containing either a math task or no task were presented in a random order.

Subsequently, a picture of a face was presented, and participants performed the gender-naming task. Following the gender-naming task, the answer of the math equation appeared on screen, such as "43", and participants had 2 seconds to judge whether it was correct by making a keyboard response. In one half of the trials, this was the correct answer, in the remaining half, the answer was incorrect. Incorrect answers deviated only slightly from correct answers, such that participants could not rely on making rough estimates.

Participants' responses and response times to the gender-naming task and the math task were unobtrusively recorded by the computer. At the end of the experimental trials, participants were thanked for their efforts, debriefed, and paid by the experimenter.

Results

Math performance. Participants solved 89% ($SD = 17$) of the math equations correctly and had an average response time of 1269 ms ($SD =$ 281). A one-way analysis of variance (ANOVA) yielded no effect of target expression on correct responses; $F(1, 40) = 1.25$, *ns*, or on response times to the math task, $F(1, 40) < 1$, *ns*. Accordingly, negative expressions did not interfere with math performance.

Gender-naming task. Incorrect responses to the gender-naming task represented only 4% of the trials, such that separate analyses of these responses would not be informative. We excluded the incorrect responses from subsequent analyses.

To analyse participants' performance on the gender-naming task, we conducted a 2 (Target Expression) $\times$ 2 (Math Task) ANOVA of participants' response times. This analysis revealed a main effect of math task, $F(1, 40) = 6.53$, $p < .05$. Participants responded more slowly to faces when a concurrent math task was present ($M = 923$, $SD = 144$) rather than absent ($M = 891$, $SD = 136$). More importantly, the analysis yielded an interaction effect of math task and target expression, $F(1, 40) = 4.74$, $p < .05$.

More focused comparisons yielded a main effect of target expression only in the trials without a math task; $F(1, 40) = 5.59$, $p < .05$. In these trials, participants responded more slowly when the expression was angry ($M = 912$, $SD = 150$) rather than happy ($M = 869$, $SD = 121$). In the trials with a math task, we found no effects of target expression, $F < 1$. In these trials, participants responded equally quickly to angry and happy faces ($M = 927$, $SD = 140$ and $M = 918$, $SD = 148$, respectively).

Removing the trials with an incorrect response to the math task from the analyses did not alter any of the above-described effects on gender naming.

Discussion

As expected, performing a math task eliminated the greater attentional interference of angry relative to happy faces in a gender-naming task. Importantly, the math task had this effect even though the task was not visually present during gender naming and even though the emotional expression of the stimuli was in the focus of the visual field. The results of Study 1 thus provide the strongest evidence to date that working-memory load moderates attentional interference of negative information. Notably, high working-memory load also resulted in a general slowdown of responses to the gender-naming task. This slowdown was likely due to the increased attentional demands of the high-load task (Barrouillet et al., 2007).

STUDY 2

We designed Study 2 to replicate and extend the findings of Study 1. Rather than manipulating the presence or absence of a working-memory load, Study 2 varied the level of working-memory load. To this end, participants retained either a 1-digit number or an 8-digit number during the gender-naming task. Varying digit span is a well-established way to manipulate working-memory load (Sternberg, 1966). If the effects of performing a math task in Study 1 were due to their differential demands on working-memory capacity, as our analysis suggests, then attentional interference of negative information should be greater while retaining 1-digit rather than 8-digit numbers. On the other hand, if the results of Study 1 were simply due to the presence of an additional task, then retaining 1-digit and 8-digit numbers should both suppress attentional interference of negative information.

Method

Participants and design

Thirty-six paid volunteers at the VU University Amsterdam (20 women, 16 men, average age 21 years) took part in the experiment. The experimental design was 2 (Digit Span: 1-digit vs. 8-digit; within participants) $\times$ 2 (Target Expression: positive vs. negative; within participants). The main dependent variable consisted of participants' response times to the gender-naming task.

Procedure and equipment

The experimental design was similar to that of Study 1. Participants again performed the gender-naming task consisting of 56 trials. This time, participants were presented with a number at the beginning of each trial, which they had to retain during the gender-naming task. We varied the working-memory load of the number task by manipulating the digit span of the number. In half of the trials (28 trials), this was a 1-digit number between zero and ten, such as "9". In the remaining 28 trials, this was an 8-digit number, such as "25371906". Trials containing a 1-digit or an 8-digit number were presented in a random order.

In each trial, following the gender-naming task, a number again appeared on screen and participants had to judge whether it was the same number as they had retained during the gender-decision task. In half of the trials, this was the same number as they had seen previously, whereas in the remaining half this was a different number. In the trials in which participants retained an 8-digit number one of the 8 digits could vary, such that participants had to retain all 8 digits in order to perform the number task effectively.

Results

Digit span performance. A 2 (Digit Span) $\times$ 2 (Target Expression) ANOVA yielded a main effect for Digit Span on participants' correct responses, $F(1, 35) = 110.93$, $p < .001$, and on participants' response times, $F(1, 35) = 806.00$, $p < .001$. Participants gave more correct responses to the 1-digit numbers ($M = 94\%$, $SD = 10$) than to the 8-digit numbers ($M = 77\%$, $SD = 11$) and participants responded faster to the 1-digit numbers ($M = 1126$, $SD = 216$) than to the 8-digit numbers ($M = 2095$, $SD = 290$).

As in Study 1, there were no effects for target expression on either correct responses, $F(1, 35) < 1$, *ns*, or response times, $F(1, 35) < 1$, *ns*.

Gender-naming task. To analyse participants' performance on the gender-naming task, we conducted a 2 (Digit Span) × 2 (Target Expression) ANOVA of participants' response times. As in Study 1, incorrect responses (4% of all responses) were excluded from the data. The analysis yielded a main effect of digit span, $F(1, 35) = 5.66$, $p < .05$. Participants were slower to respond to the faces when they had to retain an 8-digit number ($M = 937$, $SD = 131$) than when they had to retain a 1-digit number ($M = 874$, $SD = 157$). More importantly, the analysis yielded the predicted interaction of Digit Span and Target Expression, $F(1, 35) = 4.38$, $p < .05$.

Focused comparisons only revealed a significant effect of target expression in the 1-digit trials, $F(1, 35) = 4.05$, $p < .05$. When participants retained a 1-digit number, that is, when working-memory load was low, participants responded slower to angry faces ($M = 892$, $SD = 161$) than to happy faces ($M = 855$, $SD = 152$). When participants retained an 8-digit number, that is, when working-memory load was high, participants responded equally fast to angry faces ($M = 946$, $SD = 140$) and happy faces ($M = 927$, $SD = 122$), $F(1, 35) = 1.79$, *ns*.

As in Study 1, removing the trials with an incorrect response to the digit span task from the analyses did not alter any of the above-described effects on gender naming.

Discussion

The results of Study 2 thus confirmed that working-memory load moderates the greater attentional interference of negative relative to positive information. Moreover, Study 2 demonstrated that attentional interference is not merely determined by the absence or presence of a concurrent task but rather by the degree to which working memory is taxed.

GENERAL DISCUSSION

Negative information has the power to grab people's attention readily and involuntarily (Eastwood et al., 2003; Öhman et al., 2001; Pratto & John, 1991). However, this power is not without limitations. Specifically, the present research hypothesised that top-down processes that are involved in working memory may modulate preferential allocation of attention to negative emotional information. When working-memory load is low, top-down control of attention is relatively weak, and negative information may capture attention even when it is irrelevant to the focal task. By contrast, when working-memory load is high, top-down control of attention is strengthened, so that task-irrelevant negative information may no longer assume priority in attention. This reasoning was confirmed in two experiments, which demonstrated that working-memory load can eliminate the greater attentional interference of negative relative to positive information.

The present findings provide the most direct demonstration to date that working-memory resources regulate attention to negative information. Prior work has documented how visual distracters can reduce attentional interference of negative information (Erthal et al., 2005; Pessoa et al., 2002). The present work goes beyond these findings, by showing that even non-visual, purely mental forms of task load can reduce attentional interference of negative information, presumably because such task load taxes working memory. Moreover, task load can moderate interference of negative stimulus features, even when the stimulus is in the focus of visual attention. An important implication of these findings is that working memory exerts a much more pervasive influence on attention to negative information than was previously assumed.

At a more general level, the present research contributes to the theoretical integration between the literatures on working memory and emotion. Whereas traditional conceptions portrayed working memory as a "cold" cognitive system, a growing amount of evidence highlights the relevance of working memory for "hot" emotional processing (Erk et al., 2007; Van Dillen & Koole, 2007). The present work adds to these findings by proposing a key role for working-memory resources in determining whether "hot" information about potential threats in the environment gets prioritised over "cool" information that is relevant to people's ongoing cognitive tasks. As such, working-memory functions seem vital to understanding the interface between cognition and emotion.

Our findings that attention to negative information depends on working-memory resources could be considered surprising, given that the attention-grabbing power of negative information is widely assumed to be automatic (e.g., Öhman et al., 2001; Pratto & John, 1991). However, these previous accounts can be reconciled with the present findings. Under conditions of low working-memory load, negative information was found to interfere with ongoing attentional processing. The present findings thus confirm that automatic processes play an important role in quickly guiding attention towards negative information. However, as the present findings also show, negative information may cease to receive preferential attention when working memory is more fully engaged by a focal task. Attention to negative information is thus fast and unintentional, but contingent upon the availability of sufficient working-memory capacity. Consequently, attention to negative information appears to be driven by a combination of top-down and bottom-up control processes.

The relative importance of top-down and bottom-up processes in attending to negative information may vary between different persons and situations. As the present findings indicate, conditions such as greater working-memory load may increase the contribution of top-down attentional control. Other conditions, such as a higher intensity of negative information, may result in a greater contribution of bottom-up processes (Yantis, 2000), and accordingly result in a stronger negativity bias. In line with this, attentional interference of negative information is stronger for intensely negative stimuli than for mildly negative stimuli (Schimmack, 2005). A reduced capacity for top-down control may similarly result in a more pronounced negativity bias (see Eysenck, Derakshan, Santos, & Calvo, 2007; Williams, Mathews, & MacLeod, 1996). Future research is needed to gain more insight into the dynamic interplay between bottom-up versus top-down processes in attention to negative information.

So far, we have interpreted response-time differences between positive and negative emotional stimuli as an index of interference of negative information (as is conventional; see Smith et al., 2006). Because this is a relative index, it remains possible that the effects of working-memory load have been driven by an increase in attention to positive information. Nevertheless, we prefer to interpret our findings in terms of changes in attention to negative information. First, research that incorporated neutral control conditions has similarly shown load-induced reductions in attentional interference of negative information (Erthal et al., 2005; Okon-singer et al., 2007). Second, neuroimaging work indicates that increased working-memory load decreases, rather than increases, neural responsiveness to positive emotional stimuli (Erk et al., 2007). The broader literature thus supports our interpretation that working-memory load reduces interference of negative information rather than boosting interference of positive information.

The present findings mesh well with recent neuropsychological evidence for a role of corticofrontal working memory areas in attentional control of processing of negative emotional stimuli (Blair et al., 2007; Hariri, Bookheimer, & Mazziotta, 2000). For example, using functional magnetic resonance imaging (fMRI), a recent study found that high working-memory load compared to low working-memory load resulted in decreased responsivity to negative stimuli in the bilateral amygdalae (Van Dillen et al., 2008). The amygdalae enhance perception of emotionally salient events (Anderson & Phelps, 2001) and may as such facilitate bottom-up control of attention. In accord with the present findings, bottom-up facilitation of attention to negative information in the brain can be modulated by taxing working memory.

At a more general level, the present research attests to a considerable amount of flexibility in human information processing. Evolutionary forces from a distant past may have shaped the mind to prioritise negative over other types of information. Nevertheless, this prioritisation seems open to reprogramming in the present, by people's current goals and interests. Perhaps it is this capacity to flexibly reprioritise information that allows people to move beyond the perception of imminent risks and dangers to explore the promises and opportunities that the future may hold.

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